Applications of Controlled Low-Strength Materials (CLSM)
National Enrichment Facility, Eunice, New Mexico

N. Hasan, P.E., F. ASCE[1] and T. P. Gardner, P.E., M. ASCE[2]

[1]Consultant (URS-Washington Division) to LES; email: nash.hasan@wgint.com
[2] Civil Field Engineer, LES, email: tgardner@nefnm.com

Abstract

Louisiana Energy Services LLC ("LES") is currently constructing an enrichment plant (the National Enrichment Facility) in Eunice, New Mexico which is expected to become operational in 2009. The National Enrichment Facility (NEF) project is a uranium enrichment plant that, when construction is complete, will operate using centrifuge technology to provide safe, cost effective, and reliable uranium enrichment services for the civil power generation industry. A Controlled Low Strength Material (CLSM) Test Pad was installed at the NEF site during construction in December 2007 to conduct plate load tests on a 100-psi (at 7-days) CLSM mixture, evaluate the results, and provide recommendations for the use of CLSM, in lieu of compacted soil backfill, in QA Level 1 and QA Level 3 structural fill applications,

1.0 Introduction

Approximately 100,000 cubic yards of compacted backfill is required for various buildings. The compacted backfill is required below the slabs on grade, following the erection of footings and exterior foundation stem walls or retaining walls. The depth of backfill between the slab and footing varies from about 2 to 3 feet.

The quality of the local soils, consisting primarily of Silty Sand (SM), requires extra compactive effort to meet the acceptance criteria of the project earthwork specification, i.e., not less than 95 percent of maximum dry unit weight according to ASTM D 1557-00 (modified effort) (Ref 2). Consideration has been given to importing more suitable engineered sand materials to facilitate the compaction schedule; however, the imported soils would result in higher installation costs than the CLSM due to the long haul distances from suitable material sources.

CLSM (also known as flowable fill) is a cementitious material manufactured using cement, fines (fly ash and/or sand), and water mixed in a concrete plant or a truck mixer. The combined ingredients produce a flowable mixture that can be installed without compaction. After hardening, generally 6-12 hours, the material is stable in volume, and reaches a compressive strength of 50-150 psi after 28-days that can be excavated, if required. Since the 1970's, CLSM has been widely used to:

- Backfill around electrical conduits, piping; electrical duct banks; manholes, and bridge abutments
- Structural fill
- Subgrades, subbases, and/or base courses under pavements; and other applications

Use of CLSM can be justified by its flowability, ease of placement for inaccessible areas, lower installation cost, and faster construction schedule. American Concrete Institute report ACI 229R-99 (Ref 1) provides guidelines for CLSM applications including materials, mix proportions, placing, and testing requirements. Testing for CLSM mixtures is performed in accordance with ASTM test standards.

Based on data furnished by LES, the following installed costs for compacted backfill and CLSM are estimated:

- Structural Fill (local crusher fines and gravel mixture from a sand/aggregate quarry source about 25 miles south of the NEF site): $132 per cubic yard
- Structural Fill (local crusher fines (Silty Sand) from a sand/aggregate quarry source less than 1 mile north of the NEF site): $114 per cubic yard
- CLSM-1 (excavatable 1 sack mix for Duct Banks): $47 per cubic yard (using project truck mixers)
- CLSM-2 (2 sack mix for Structural Fill): $53 per cubic yard (using project truck mixers)

The lower strength CLSM-1 is being used for backfilling pipes and conduit trenches, and around manholes at the NEF site. This mixture, which was qualified after site tests on flowability, unit weight, and compressive strength tests, including trench excavatability, reaches 20-40 compressive strength at 28-days. On April 30, 2007 LES Field Engineering published a position paper on the use of CLSM at the NEF site. Since its approval in June 2007, over 38,000 cubic yards of CLSM-1 has been placed to date.

Use of 2-sack, 100-psi (at 7-days) CLSM mixture (CLSM-2) within the footprints of both QA Level 1 and QA Level 3 buildings was subject to approval by the plant design consultant, based upon the successful completion of plate load tests on the specially constructed CLSM-2 Test Pad. Since its approval in January 2008, over 20,000 cubic yards of CLSM-2 and CLSM-2.5 has been placed to date.

2.0 Construction of CLSM-2 Plate Load Test Pad

As shown in Figure 1, a plate load Test Pad (approximately 25 feet wide x 120 feet long x 4 feet deep) was constructed using CLSM-2 in accordance with a CLSM Test Plan, dated December 11, 2007 approved by LES Field Engineering.

The CLSM-2 was placed from the north end to the south end of the Test Pad in two lifts (total 4 feet) via pumping. The time interval between the two lifts was approximately 21 hours.

The first CLSM-2 lift, placed on December 11, 2007 reached a height of 24-36 inches across the Test Pad length (300 cubic yards). The placement rate, which averaged 75 cubic yards per hour, demonstrated the suitability of the CLSM mixture proportions for pumping.

The second and final CLSM-2 lift (140+ cubic yards) was placed on December 12, 2007 reaching a final height of 4 ft across the Test Pad in a little over 2 hours. Only the final lift surface was bull floated.

3.0 CLSM-2 Mix Design

CLSM-2 mixture proportions for structural fill were determined from CLSM trial batches, performed on-site, using Type II/V cement, crusher fines (minus 3/8-inch or minus 3/16-inch), water, and air-entraining admixture. All material sources, with the exception of the crusher fines, are from the dedicated sources for the production of QA Level 1 and QA Level 3 concrete at the NEF site.

The 3/8-inch crusher fines are being produced in limited quantities (300 cubic yards a day), whereas 3/16-inch crusher fines are available already processed and stockpiled nearby (over 200,000 cubic yards).

CLSM-2 proportions were designed to produce a flowable mixture suitable for placement without compaction. The average properties of the mixture immediately after batching were: 9.5 inches slump (ASTM C 143), 5.1% air (ASTM C 231), and 116 lb/ft^3 unit weight (ASTM C 138). The average properties of the mixture after pump discharge were: slump 6 inches, flow (ASTM D 6103) 6.25 inches, and unit weight 119 lb/ft^3. CLSM mix proportions were designed to produce compressive strength of 80-100 psi minimum at 7-days, and a 120-150 psi range at 28-days.

After batching the materials into a truck at the site batch plant during construction of the Test Pad, a minimum of 100 revolutions at mixing speed were considered necessary to assure proper dispersing and mixing of cement.

The recommended CLSM-2 mix proportions are presented In Table 1.

Table 1: CLSM-2 Mixture Proportions (per cubic yard)

Material	Weight
Cement (Type II/V)	188 lbs.
Crusher fines, 3/16-inch	2400 lbs.
Water	541 lbs. (65 gallons)
Air entraining admixture	5 oz.

4.0 CLSM-2 Testing

Sampling and testing of CLSM-2 mixture for the Test Pad were performed every 50 cubic yards at two (2) locations, including, at the batch plant immediately after mixing in a truck mixer and at the end of the pumpline discharge. At the batch plant, tests for slump, unit weight and air content were performed and seven cylinders for compressive strength tests were made. At the pumpline discharge, only tests for flow, slump and unit weight were performed.

CLSM-2 samples were poured into cylindrical 6x12-inch molds (pre-split and taped) without rodding or tapping, in accordance with ASTM D 4832. The cylinders were air cured at the site testing agency laboratory. The cylinders were tested for compressive strength at 4, 5, 6, 7 and 28-day ages. At the required age, the specimens were carefully removed from the molds, allowed to dry at room temperature for 4 hours, and the ends of specimens were ground prior to testing. Some specimens were fragile at early ages and indicated small voids and entrapped air, after stripping.

CLSM-2 strength tests were performed at 4, 5, 6, 7, and 28-days. The 7-day compressive strength for all tests averaged 78 psi (range: 60 to 93 psi), while the air entrainment for the mixture ranged from 4 to 6% (average: 5.1%). The 28-day compressive strength for all tests averaged 150 psi (range: 136-168 psi).

In addition, 6x12-inch cylindrical specimens were cast every 50 cubic yards, to verify settlement characteristic after hardening. The specimens were stored on-site and field cured without protection for four (4) days then transported to the laboratory for environmentally controlled curing and testing. The vertical settlement or shrinkage of the CLSM-2 mixture was determined from readings taken on the cylindrical specimens at ages ranging from 2 to 41 days after placement. The initial settlement after 3 days ranged from 0.083-0.149 inch. The settlement readings essentially remained unchanged after 7 days.

Bleeding of the CLSM-2 mixture was determined in the laboratory using a 1-liter (1000cc) graduated cylinder. The amount of bleed water was measured with time. After 100 minutes, the amount of bleeding was 10 cc or 1%. No further bleeding was observed, and the test was discontinued after 160 minutes.

5.0 Plate Load Tests

Nonrepetitive static plate load tests performed at the NE, NW and SE locations of the CLSM Test Pad in accordance with AASHTO Designation T222-81 (2004) (Ref 3). The results of the plate load tests modulus of subgrade reaction (k_U) values, performed 6 to 8 days after the installation of the CLSM-2 Test Pad, ranged from 625 to 780 pci.

6.0 Discussion of Results

Various design issues and concerns have been raised by the LES Project Team and consultants. These issues and concerns, based on onsite tests results, literature search and conversations with experienced engineers and researchers, involved in the use of CLSM are addressed below:

Bleeding and Settlement:
Due to large amount of water in CLSM mixtures required to provide flowable consistency, there is inherent bleeding and settlement prior to hardening. Published data on shrinkage/settlement of the CLSM mixtures are limited.

ACI 229R-99 (Ref 1) states "Subsidence deals with reduction in volume of CLSM as it releases water and entrapped air through consolidation of the mixture….Most of the subsidence occurs during placement and the degree of subsidence is dependent upon the quantity of free water released. Typically, subsidence of 3 to 6 mm (1/8 to 1/4 inch) per foot of depth is reported. This amount is generally found with mixtures of high water content. Mixtures of low water content undergo little or no subsidence."

For the CLSM-2 mixture used for the Test Pad (based on measurements taken on 6x12 inch cylinders) the average settlement was 0.11 inch after 22 days. This CLSM mixture had a water to cement ratio (w/c) of 2.9.

Shrinkage and Cracking:
According to Ref. 1, shrinkage and cracking cracks do not affect the performance of CLSM. Ultimate linear shrinkage is reported to be in the range of 0.02-0.05%. Minor linear shrinkage cracking was observed in the surface of the first lift ranging in width from about 1/8-inch to 1/4-inch. The measure depth of the cracks was about 3 5/8-inches. Negligible linear hairline cracking was observed in the surface of the bull floated final lift.

Compressive Strength:
The compressive strength of the CLSM mixture is a function of the cement content and water to cement ratio. For CLSM containing 1-sack cement, the 28-day compressive strength is about 30-50 psi. Addition of fly ash to the CLSM mixture is expected to improve the long term compressive strength, which would typically produce strengths 25% higher (at 90-days) than the 28-day value.

For the 2-sack CLSM-2 mixture, the average 7-day compressive strength was 78 psi (range: 60-93 psi), while the average 28-day compressive strength was 150 psi (range: 129-168 psi). The 7-day strength is about 50% of the 28-day strength. Since no fly ash is included in this mixture, significant strength gain beyond 28-day age is not anticipated.

The CLSM mixtures with compressive strengths up to 150 psi are considered excavatable using hand equipment, but at higher strength, the CLSM requires heavy equipment (a backhoe) for excavation (Ref 1). New Mexico DOT limits the 28-day compressive strength for CLSM to150 psi maximum where used for backfill in culvert installations or backfilling pipes. The requirement for excavatability beneath structure slabs of a CLSM structural fill or base course mixture using a compressive strength of 150 psi or less is not applicable at the NEF as we do not intend on excavating the CLSM placed.

Plate Load Tests:

The minimum corrected modulus of soil reaction k_U value required by the project earthwork specification is 100 pci. Plate load tests performed at the NW and NE locations of the Test Pad yielded k_U values of 625 and 640 pounds per cubic inch (pci), respectively. These values correspond to an average CLSM-2 compressive strength of 78 psi at about 7-days. The plate load test at the SE location was performed on CLSM-2 after 8 days and reflects a 20% higher k_U value (i.e., 780 pci) which is estimated to correspond to higher in-situ strengths (i.e., 90-100 psi). The plate load tests on conventionally compacted crusher fines (Silty Sand), performed in November 2007, yielded k_U values of 320, 400, and 425 pci.

Batch Plant Upgrade:

To meet the project CLSM daily placement rates, a semi-automatic batch plant (Cemco) was erected adjacent to the NEF site, with the following upgrades:

- Provide water storage tanks with pumps to reduce batching time.
- Increase the capacity of the water supply pipeline to the site batch facility.
- Install a software system for automatic printing of batch tickets.
- Calibrate scales to assure accurate batching tolerances for cement, fines, and admixture.
- Maintain uniformity of the 3/16-inch fines stockpile by not allowing more than 30% passing the No. 200 sieve

7.0 Conclusions and Recommendations

1. While a low compressive strength (20-40 psi) CLSM-1 mixture is suitable for general backfilling around pipes and conduit trenches, and around manholes, a higher compressive strength (CLSM-2) of at least 200 psi at 28-days is required for use as structural fill applications:

   a. Beneath floor slabs of QA Level 3 buildings, and

   b. Beneath floor slabs of specifically defined areas of QA Level 1 buildings

   CLSM was not approved on the project for use as structural fill_beneath any footings. For such applications, it would have required additional considerations (such as soil to structure interaction analysis).

2. The settlement data for field cured cylinders confirmed that the bleeding and settlement of the CLSM mixture is essentially complete upon hardening. The average settlement for 12-inch high cylinders, immediately after hardening, and after 7 days, is 1/8-inch. The settlement after 7 days remained unchanged.

3. To minimize variation in consistency and strength, the CLSM-2 mixtures should:

   a. Have the total water adjusted for free moisture in the fines

   b. Yield an average strength appreciably higher than the minimum specified strength

   c. Ensure the crusher fines (minus 3/16 material) has adequate percent passing No. 200 sieve (i.e., 30% or less) to provide cohesiveness and flowability to the mixture without segregation or excessive bleeding.

   d. Include the use of an air entraining admixture to reduce bleeding and facilitate pumping of the CLSM-2 mixture.

   (**NOTE:** Subsequent to the plate load pad tests, it has been determined that increasing mixing of the CLSM-2 in a truck mixer, from 100 to a minimum of 150 drum revolutions prior to discharge, eliminates lumps and improves uniformity of the mixture. The CLSM-2 mixture was found pumpable without the need of initial priming grout.)

4. The plate load tests, performed on the CLSM-2 mixture yielded k_U values of 625, 640, and 780 pci (average 680 pci), which are about 1.75 times greater than the earlier results on the approved conventionally compacted structural crusher fines (Silty Sand) fill material which yielded k_U values of 320, 400, and 425 pci (average 380 pci). The average 680 pci value is also about 6.8 times greater than the required specification design value of 100 pci.

5. Based on a automatic batch plant, CLSM production and placement rates of up to 75 cubic yards per hour are considered feasible and sustainable, provided adequate number of truck mixers are available.

6. It is recommended to install CLSM structural fill using an approved placing procedure for optimum results. The placing procedure should address lift height, time interval between lifts, cold weather protection, and other related issues. Some of the recommendations are:

   a. Lift Height: Place CLSM in lifts not exceeding 2 feet using a sloping-stepped pattern, to minimize bleeding and settlement of the lift.

   b. Time Interval between Lifts: Minimum 4 hours. At ambient temperatures of 40°F or lower, this time interval may be increased to 12 hours, prior to placement of the successive lift.

   c. Finishing: screeding and bull floating of the CLSM is recommended for the final lift only, immediately below the structural concrete to provide a uniform level working surface.

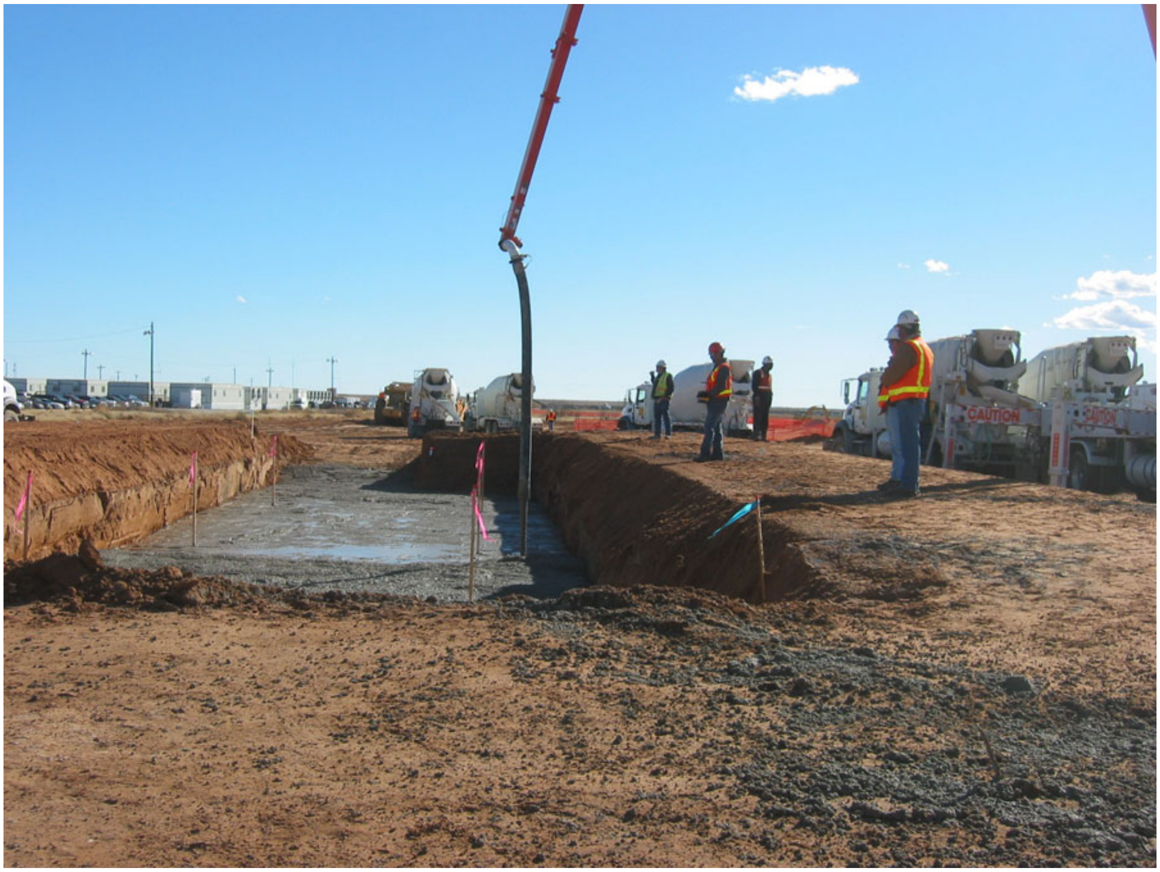
   d. Sequencing and Placement of CLSM: It should be placed in areas 10,000 sq/ft or less in a single lift of 2-ft for each planned placement. CLSM should not be placed adjacent to freshly placed CLSM until the time interval described in paragraph 9.b above has expired.

   e. Curing: To minimize drying shrinkage of the final lift, protection by wet burlap, curing compound, or plastic sheeting after the finishing of final lift is recommended.

   f. Differential Settlement: To minimize differential settlement, CLSM should not be placed in areas adjoining compacted soil backfill, without additional analysis.

   g. Provide a bond breaker between CLSM and adjacent concrete structures, such as footings, stem walls, retaining walls, etc, to prevent CLSM from bonding to those structures.

Figure 1
CLSM-2 Plate Load Test Pad Construction
National Enrichment Facility, Eunice, NM



7. References

1. ACI 229R-99, Controlled Low-Strength Materials, Reported by ACI 229 Committee
2. ASTM D 1557-00 - Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3) or (2,700 kn-m/m^3))
3. AASHTO T222-81 (2004), Standard Method of Test for Nonrepetitive Static Plate Load Test of Soils and Flexible Pavement Components for Use in Evaluation and Design of Airport and Highway Pavements.